Researching Locally, Thinking Globally: Carbon Flux from Soil in Suburban Maryland

Independent Project

Spring 2011

Darci Ferrer

Professor Katalin Szlavecz

Johns Hopkins University

Abstract

With expanding urbanization, there has been an increase in manipulation of the environment by activities such as construction and landscaping. The consequences of these alterations on carbon efflux are important in understanding urban impact on the global carbon cycle from soils. This study aims to help quantify carbon efflux in urban soil from different land covers over a 6-month time span. Using a standard chamber method carbon efflux was recorded for 12 different sites over 3 different land covers. No difference in carbon efflux amongst the land covers was found, most likely due to the high variation among samples. The data suggests with further research and more troubleshooting significant differences will be seen in the warmer seasons between the cover types.

Introduction

Land use changes in urban environments are contributing to the alteration of local and regional carbon cycling. As cities expand, soil is disturbed by anthropogenic activities leading to erosion, topsoil removal, and oxidation (Pouyat et al., 2010), factors known to impact carbon storage. Globally most (over 50%) people live in urban areas (United Nations, 2009). Carbon (C) released from terrestrial sources is about 50 to 70 Pg C per year, significantly more than the amount released from fossil fuels (Ma et al., 2005). Terrestrial sinks would need to store about 1.4 Pg C per year to negate annual increase in emissions. Land alterations have instead caused an increase in CO_2 from soil, with 1.7 Pg C per year emitted (Laurila, 2002).

Soil efflux is the quantity of carbon dioxide released from the soil surface due to complex interactions of physical, chemical and biological processes. Sources of carbon flux include microbial activity, chemicals released from roots and mineral oxidation (Uusimaa, 2003). Moisture and temperature affect soil respiration, both of which are influenced by seasonality (Tang, 2005). For example, with decreased moisture content, microbial activity slows down reducing CO_2 flux.; while an increase in temperature will result in an increased rate of carbon emissions from soil. However, these relationships do not hold at extreme temperature and moisture conditions.

Proper land management practices can help to repair the impacts on carbon in soils. The Baltimore Ecosystem Study (BES) (www.beslter.org) found that retired agricultural lands have been able to improve carbon storage over time. As part of the mitigation plan to reduce green house gas emissions, the Kyoto Protocol suggests finding terrestrial sources that could store or uptake carbon to help reduce emissions into the atmosphere (UNFCCC, 1997), such as the type of vegetation cover and planting trees (Pickett et al., 2008). Urban soils vary drastically in composition and cover. More knowledge is needed about carbon flux and land covers to discover the best practices for carbon mitigation.

This study examines carbon efflux from soils, with different land covers in the urban environment. The type of cover hints at possible anthropogenic influences that may have disturbed the soil. For example, intermediate land cover between property lines may contain mulch, English ivy, and leaf litter. This suggests the land has been modified more so than the forest located at the same site. We would expect that soil with the most modification would contain less carbon and therefore would have lower carbon flux than other, less disturbed soils. Determination of differences in carbon emissions from urban land cover helps to identify potential sinks and sources of increased emissions. Influences of moisture and temperature on carbon flux were also investigated. It is known that both moisture and temperature influence carbon flux from soils (Groffman et al., 2006) and Microbial activity (Ashman, 2002). We set out to quantify these influences at Cub Hill.

Materials and Methods

Study site

The Cub Hill site is located 14 km from the center of Baltimore City, MD. The site has several ongoing studies related to the Baltimore Ecosystem Study including the first permanent carbon flux tower in an urban/suburban environment. The site was selected because of the juxtaposition of an available tower to forest and residential areas (Figure 9). To the North and West of the tower location is a poplar-oak-hickory stand with a canopy height of 20-26 meters. To the south is a mix of medium density residential areas made

Figure 9. Land use map of Cub Hill (created by R. Pouyat and I. Yesilonis and J. Russell-Anelli)

up of several subdivisions built in the 1970's and 80's. Measurements on the tower include net CO_2 exchange, input and partitioning of radiation (net, solar, PAR, IR, and UV), 3-D wind speed and direction, precipitation, relative humidity, and air temperature. Other projects in the area include soil mapping, stream monitoring and social surveys.

The tower continuously monitors carbon flux in the surrounding atmosphere. The tower, just the total amount, does not determine the source of the carbon dioxide emissions. This study will quantify the amount of carbon dioxide released from the soil near the tower.

Since 2008 a wireless sensor network system consisting of 53 units has been monitoring soil temperature and moisture at different land use types (http://www.lifeunderyourfeet.org/en/deployment/default.asp#cubhill).

Materials

To obtain carbon dioxide emission data at each plot, a standard chamber method was used with Vaisala CARBOCAP carbon dioxide probe GMP343 (see figure 3). Rings of cut PVC pipe (15 cm in diameter, 6 cm high) were installed into the ground at each selected plot. The chamber (15 cm diameter, 12 cm high) contained the probes and fit snuggly on top of the installed piping. The probes connected to an Acer netbook, which recorded the carbon dioxide emissions. Data from permanent installed sensors was downloaded from November 2010 until April 2011, the time period which carbon flux was sampled

Methods

All plots chosen were at the Cub Hill site, within 2.18 acres of land. Soils are very heterogeneous, so having the plots near each other in order to minimize variability. No control sites were chosen as each plot was being monitored and must not be disturbed or altered. Data was reviewed regularly and assessed for any outliers for quality assurance.

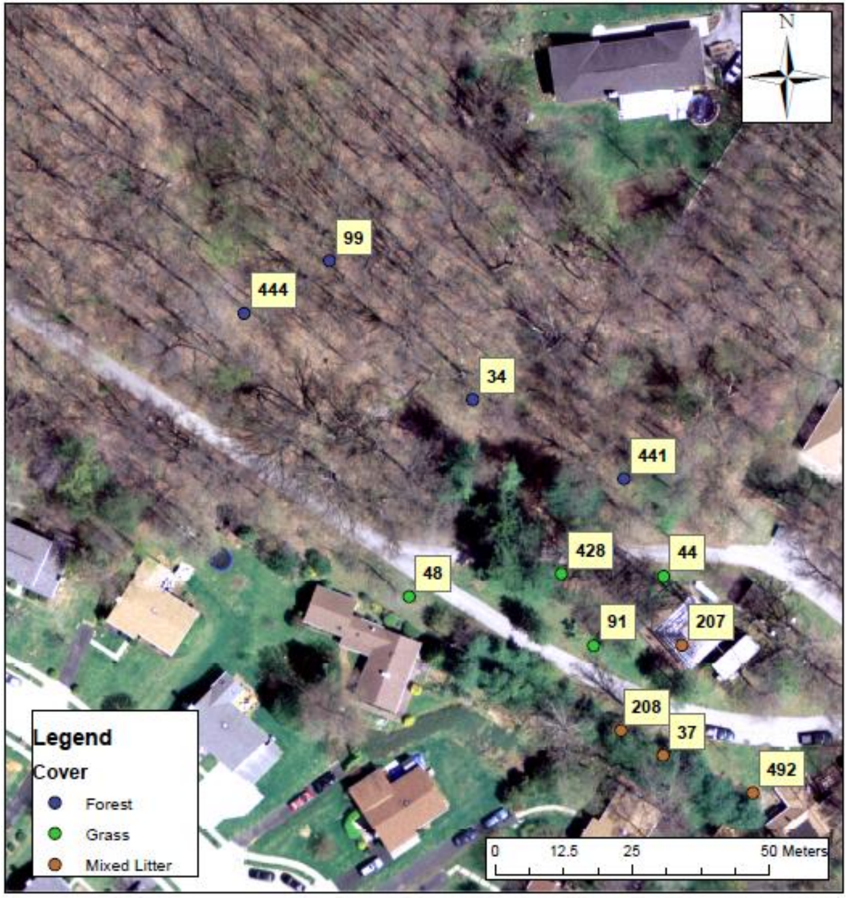

Figure 1. Ariel View of Cub Hill with Plots Depicted by Land Cover

In total, 12 plots were selected at random, each nearby the pre-existing sensors. At each of these plots, two sub-plots were chosen within 2 meters apart. This allowed for 2 readings at each plot (see Table 1 in Supplemental Data). There were 4 plots at each of the following land covers: forest, grass, and mixed (see Figure 1). The mixed ground cover varied at each plot. It consisted of a combination of mulch, English Ivy, shrubs and trees (see Figure 2). Carbon dioxide emitted from the soil was measured in units of ppm/s for 8 minutes per plot.

Data was taken at each plot approximately one day per week from November of 2010 through April 2011 between the hours of 10 am and 2 pm. Due to technological restraints, data sampling did not occur when there was precipitation or too much snow accumulation. Time of data collection was important because carbon emissions correlate to temperatures and peak temperatures occur between those hours.

Data analysis

Data was analyzed using Microsoft Excel and the statistical program, R[1]. The raw data measured by the probes is in the quantity of ppm/s of CO_2. The R program was used to calculate and plot the raw data to find linear regression and flux. Carbon efflux was calculated using the formula (Hutchinson and Mosier, 1981; Szlavecz et al., 2010):

$$F=\frac{dC}{dT}*\frac{V}{S}$$

Meaning CO_2 flux (F) in units of µmol $m^{-2}s^{-1}$ is equal to the molar concentration (C) over time (T), multiplied by the volume of headspace (V) over the area of surface soil (S). The first 3 minutes of each sample was discarded due to the initial irregularities in measurements (see Figure 4). Linear regression was used to determine outliers, since it is expected to be around 0.99 (Szlavecz, 2010). An excel file was created after the R calculations allowing for further

[1] *More information on this software can be found at* www.**r**-project.org/

analysis in the excel platform. Data was plotted on a weekly basis in excel to determine any outliers and identify inconsistencies amongst replicate plots.

Figure 2. A plot containing mixed cover

Figure 3. Vaisala CARBOCAP carbon dioxide probe setup

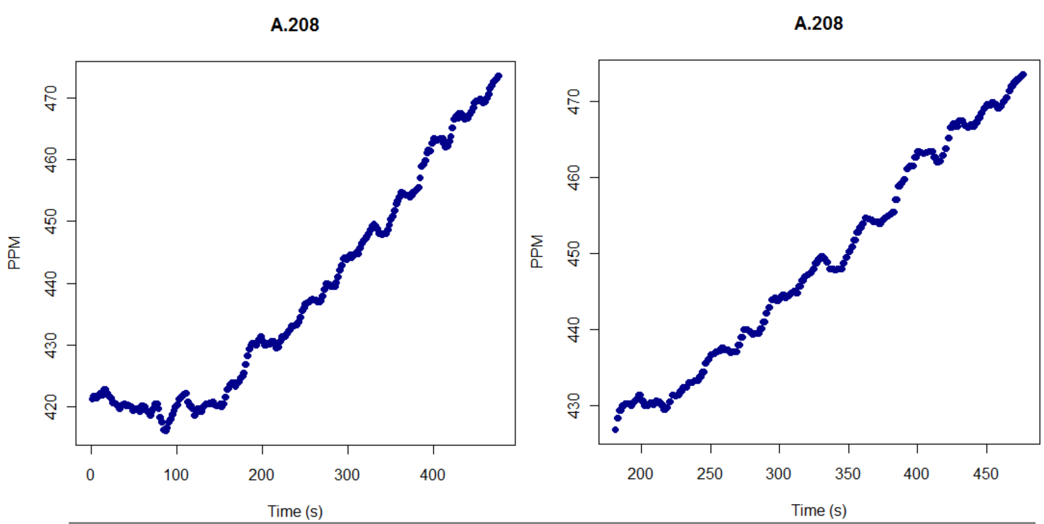

Figure 4. Raw CO_2 emissions before (Right) and after (Left) first 3 minutes are removed for a plot

Soil temperature at 10 cm depth and moisture data was extracted from Grazor and analyzed using the Microsoft Excel platform. The data was plotted to show trends over time. No further statistical analysis was conducted due to inconsistencies and gaps in the data record.

Results

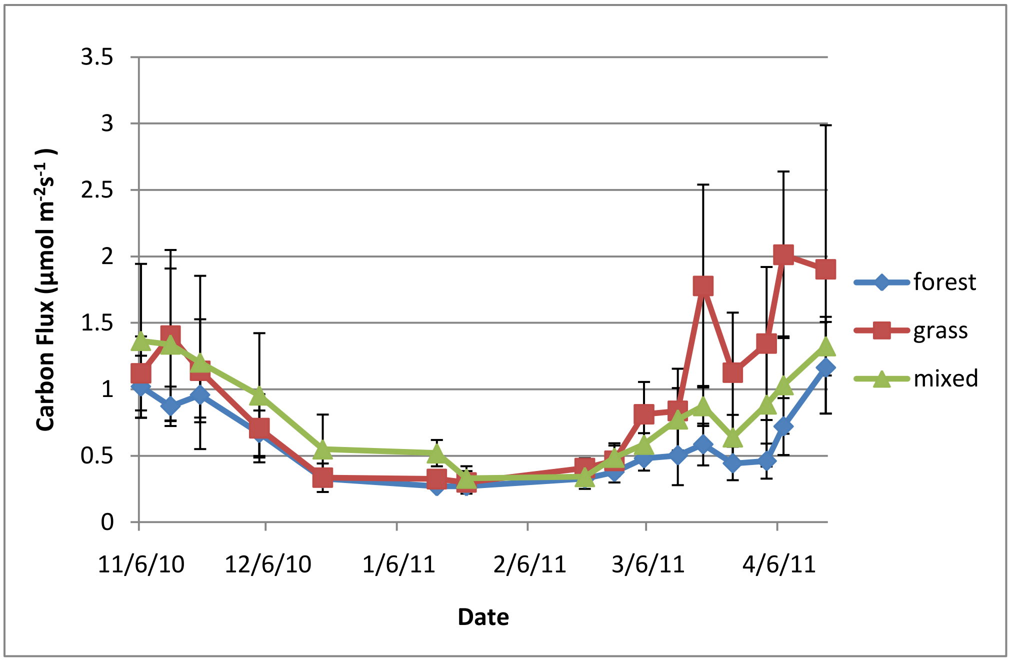

Figure 5. Carbon efflux per land cover over time

Using R, the differences in CO_2 efflux among land covers at Cub Hill were analyzed using ANOVA (Table 1). No significant differences in carbon flux were observed among land cover types. There was large variability among the data points within each soil cover group (Table 2., Figure 5). Significant changes were shown with CO_2 flux within each cover group as time progresses. This means that differences are seen with flux within each specific land cover, so the carbon efflux is not constant. This is consistent with the change of seasons over the duration of the study since temperature is increasing (Figure 6, 7.)

Table 1. ANOVA between cover types and time (by day)

	Mean	F value	P
Cover	3.3365	2.9574	0.1628
Day	0.8258	0.7320	0.5847
Cover * Time	0.7662	0.6791	0.5573

Table 2. ANOVA within cover types and analyzed over time (by day)

	Mean	F value	P
Day	2.85797	51.7787	< 0.001
Cover * Time	0.16341	2.9606	< 0.001

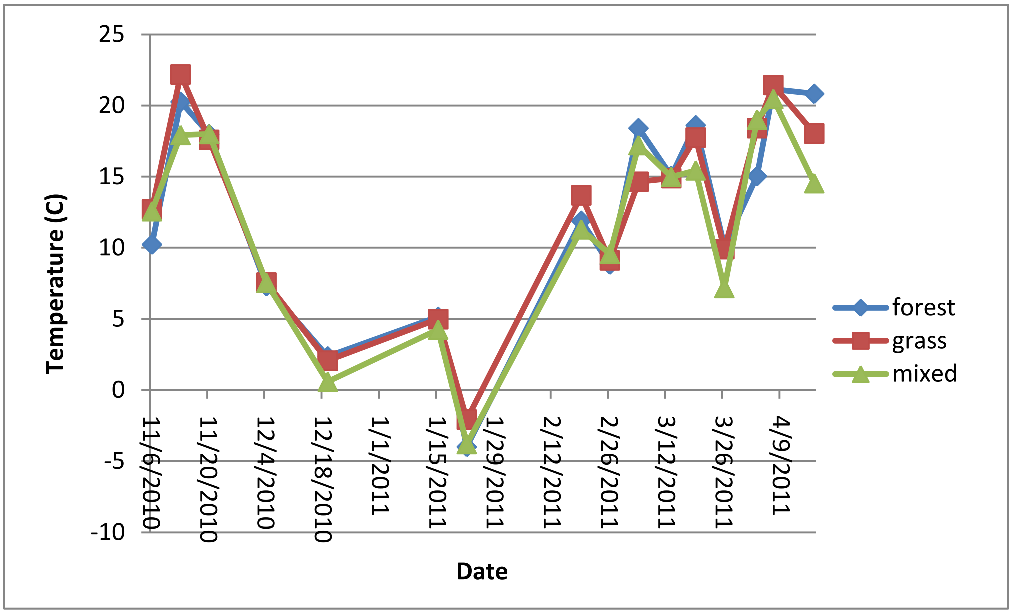

Figure 6. Surface temperature within the chamber as measured over time

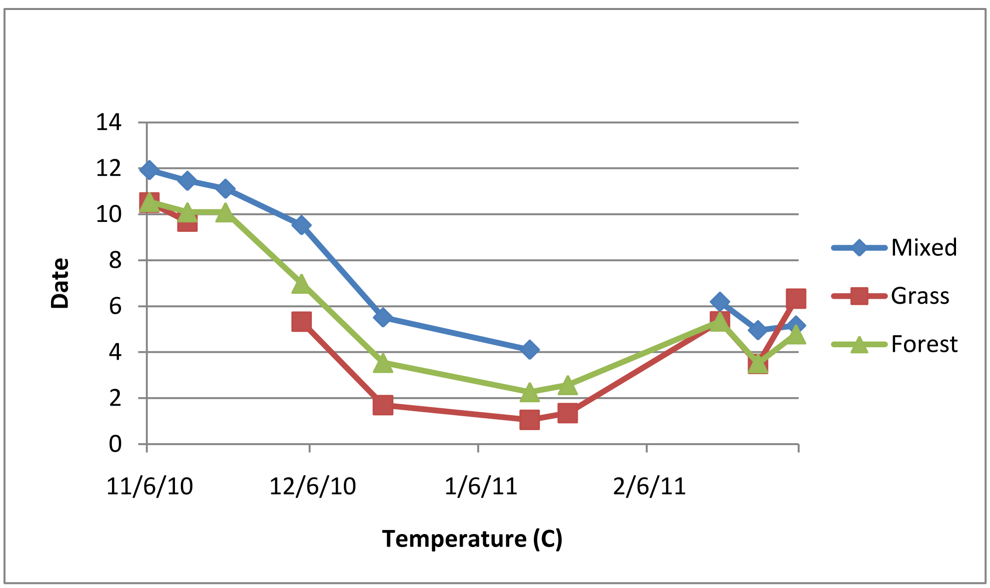

Figure 7. Soil temperature at 10 cm depth as measured over time per land cover

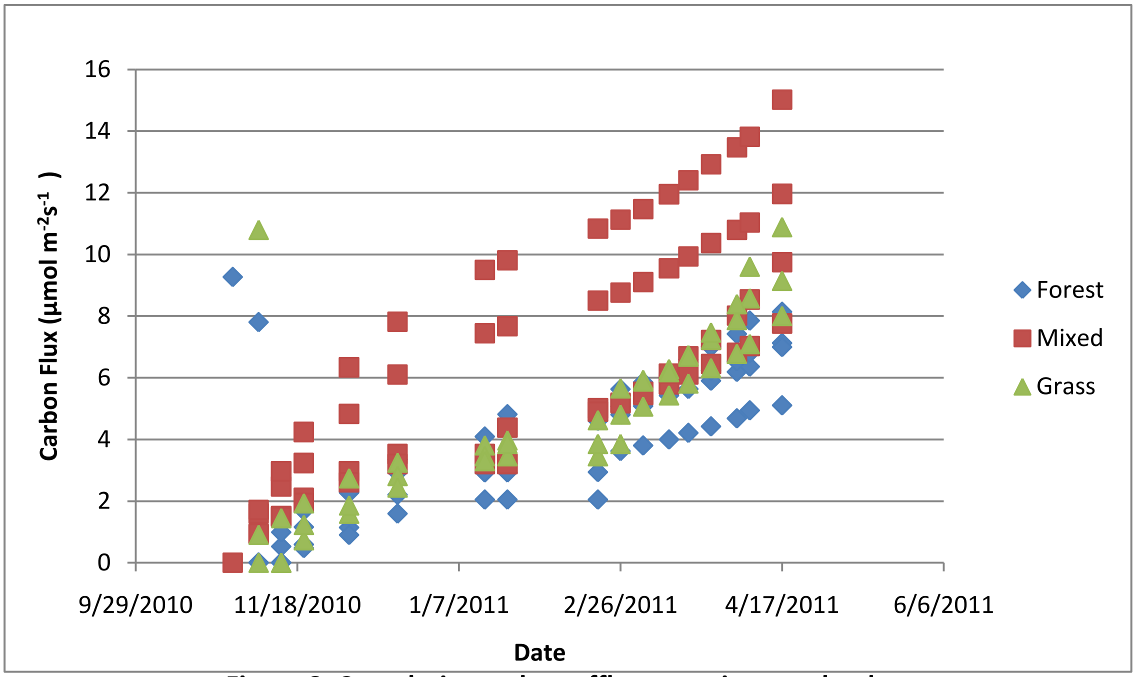

Figure 8. Cumulative carbon efflux over time per land cover

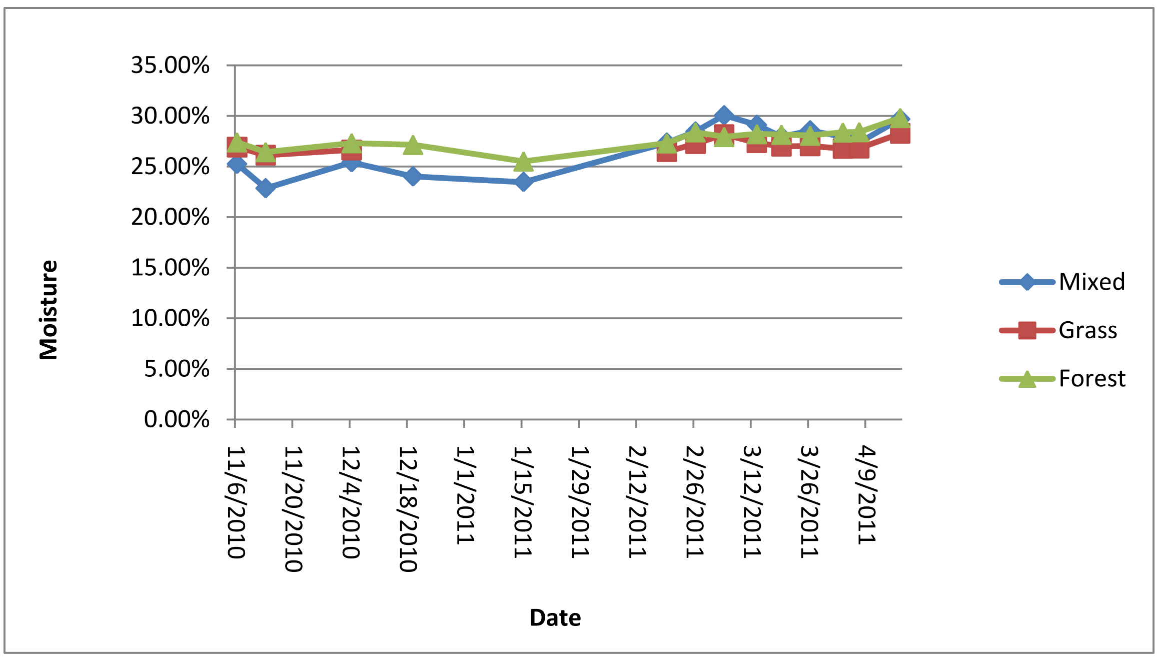

Figure 9. Soil moisture per land cover measured by sensors over time

To determine possible influences of moisture and temperature on carbon efflux, data from Grazor was plotted. Soil temperature (Figure 7) was less extreme than air temperature (Figure 6) with very low temperatures in January and did not increase until March. Soil moisture measurements taken by the sensors found much consistency among the land covers (Figure 9).

No statistical analysis was conducted for the Grazor information, due to missing information in the data at the time of the download.

Discussion

Land cover (forest, mixed and grass) in this study was not shown to have significantly different amounts of carbon efflux when compared to each other. Moisture qualitatively appears to be consistent throughout the duration of the study for all cover types. There were periods of high rain in the spring but it was not reflected in the moisture content recorded by the sensors. Temperature played a large role in the small amount of efflux recorded throughout the winter months. The likely reasons as to why no statistical differences among the cover types were found would be the heterogeneity among the rings at the site. The data shows that carbon efflux is changing over time amongst all groups. It is probable that over the warmer season significant differences among cover types will be seen with increased carbon efflux.

This study was relatively short, spanning a course of 6 months with much variability among the replicates within the land covers. To get a clear picture of carbon efflux from different land covers, sampling needs to be continued year round. More research is being conducted at Cub Hill with data collection of carbon flux. Even though soil moisture measurements obtained through Grazor appear relatively consistent to each other (Figure 9), soil moisture readings conducted for trouble shooting within the installed rings showed much more variability. Shading, gradient, and flora contributed to these differences among replicates at the same plot. The variability, exceptionally cold season and lack of data for spring likely contributed to the lack of significance shown between the cover types with carbon efflux.

Since this study occurred mostly in colder months, microbial activity is expected to be a large contributor to carbon dioxide released from the soil compared to other factors such as root respiration. We would expect to find the soil temperature higher in grasslands than forests (Savva et al., 2009) but due to a lack of data, this was unable to be determined. Most efflux in the winter months would be due to microbial activity, which is influenced by factors of moisture and temperature.

This past winter was exceptionally cold and snowy so the results found of carbon efflux are not likely to be typical[2] for December and January. Temperatures in the Baltimore area in December (2010) averaged a high of 39.9 compared to the 2009 high of 42.5. This decrease in temperature both compared to the previous year and historically continued through January. January also saw an increase in snowfall with 10.7 in higher than usual snowfall compared to the normal anticipated of 7.0 in. Since the snow accumulation in the area was substantial from

[2] Based on preliminary data from the National Weather Service (http://www.weather.gov/climate/index.php?wfo=lwx)

January into early February, not all of the plots or sub-plots were sampled constantly during that time span. If the PVC piping was undetectable by snow or the snow was too high in the ring and risked damaging the sensor, data was not taken at that site (See Table 1 in Supplemental Data).

The methods used for this study are well established and likely to continue to be utilized. A similar but larger analogue study at Penn State University (Byrne et al., 2008) utilized the same chamber method. In that long-term study (3 years) land covers were examined, carbon flux and temperature were measured on a more microscopic scale than this study. The experimental site in the Byrne study was not in an urban environment to lessen the variability in the experiments. As a control, researchers used an unmowed plot. The Cub Hill site on the contrary is urban, with three different land covers being monitored. No control plot was established since we did not want to alter the conditions that already existed. Small variations in disturbance exist inevitably, by the placement of chamber onto the piping (Tang, 2005) potentially moving the soil beneath it. The removal of the first 3 minutes of data from the sampling in our study helps to negate any possible soil disturbance.

The study will continue at Cub Hill with measurements of carbon efflux being obtained through at least October of 2011. With more readings in spring, most likely an increase in temperature and soil moisture will be seen, increasing carbon efflux through the summer season. Since Cub Hill is extensively studied, this data will contribute to our understanding of carbon flux in soils.

Conclusion

This study will help researchers better understand carbon flux on a local scale. Since soil is very heterogeneous and influenced by many variables, there is much difficulty extrapolating observed carbon flux from a local to a global scale in general. The specific contribution of this study is the exploration and troubleshooting of suitable sampling plots in Cub Hill. Inevitably unexpected challenges arose, such as tulips germinating in one of the rings but not in the replicate. Ultimately what this study will help accomplish is a baseline for the readings observed at the Cub Hill tower to help provide a general understanding on how groundcover influences carbon flux readings. This study will also be another step to determining better land management practice locally such as appropriate land cover for the gradients on property lines or landscaping.

Acknowledgements

I like to extend special thanks to Dr. Katalin Szlavecz[3] and Dr. John Hom[4] for allowing me to participate in this project. Thank you to the entire Szlavecz lab, in particularly Lijun Xia and

[3] Johns Hopkins University

Michael Bernard for their technical and statistical expertise. I would also like to thank Dr. Eileen McGurty[5] for her guidance and advice.

References

Ashman, M., Geeta P. 2002., *Essential Soil Science.* Blackwell Publishing.

Byrne, L., Bruns, M., & Kim, K., 2008. Ecosystem Properties of Urban Land Covers at the Aboveground–Belowground Interface. *Ecosystems* , 1065-1077.

Pouyat, R.V. and Effland, W.R. 1999. The investigation and classification of humanly modified soils in the Baltimore Ecosystem Study. Pages 141-154. In Kimble, J.M., R.J. Ahrens, and R.B. Bryant (eds.). Classification, Correlation, and Management of Anthropogenic Soils, Proceedings--Nevada and California, September 21-October 2, 1998. USDA Natural Resource Conservation Service, National Survey Center, Lincoln, Nebraska.

Graham, L. E., Graham, J. M., and Wilcox, L.W. 2006. *Plant Biology.* Upper Saddle River: Pearson Prentice Hall.

Groffman, P.M., Pouyat, R.V., Cadenasso, M.L., Zipperer, W.C, Szlavecz, K., Yesilonis, I.D., Band, L.E., and Brush, G.S. 2006. Land use context and natural soil controls on plant community composition and soil nitrogen and carbon dynamics in urban and rural forests. *Forest Ecology and Management* , 177-192.

Hutchinson G.L. and Mosier A.R. 1981. Improved cover soil method for field measurement of nitrous oxide fluxes. Soil Sci Soc Am J 45:311-316.

Laurila, T. 2002. *Vaisala News Articles.* Retrieved December 2010, from Carbon Cycles of the Ecosystems of the World : http://www.vaisala.com/Vaisala%20Documents/Vaisala%20News%20Articles/VN160/Surge_in_studies_on_Carbon_Cycles_of_the_Ecosystems_of_the_World_vn160.pdf

Ma, J., Butnor, J., North, M., Euskirchen, E. and Oakely, B. 2005. Biophysical Controls on Soil Respiration in The Dominant Patch Types of an Old-Growth, Mixed-Conifer Forest. *Forest Science* , 221-232.

National Weather Service Forecasting Office. (n.d.). *Baltimore/Washington*. Retrieved from Observed Weather Reports: http://www.weather.gov/climate/index.php?wfo=lwx

Pickett, S.T., Cadensasso, M.L., Grove, J.M., Groffman, P.M., Band, L.B., Boone, C.G., Burch, W.R., Grimmond, S.B., Hom, J., Jenkins, J.C., Law, N.L., Nilon, C.H., Pouyat, R.V., Szlavecz, K., Warren, P.S., Wilson, M.A. 2008. Beyond Urban Legends: An Emerging Framework of Urban Ecology, as Illustrated by the Baltimore Ecosystem Study. *BioScience* , 139-150.

[4] US Forest Service
[5] Johns Hopkins University, AAP

Pouyat, R., Groffmanb, P., Yesilonisc, I., & Hernandez, L. (2002). Soil carbon pools and fluxes in urban ecosystems. *Environmental Pollution* , 107-118.

Pouyat, R., Szlavecz, K., Yesilonis, I., Groffman, P., & Schwarz, K. (2010). Chemical, Physical, and Biological Characteristics of Urban Soils. In J. A.-P. Volder, *Urban Ecosystem Ecology* (pp. 119-143). Madison: American Society of Agronomy, Crop Science Society of America, Soil Science.

Raven, P., Evert, R., & Eichorn, S. 1992. *Biology of Plants* (5 ed.). (S. Anderson, Ed.) New York, New York, USA: Worth Publishers.

Savva, Y., Szlavecz, K., Pouyat, R., Groffman, P., and Heisler, G. 2009. Effects of Land Use and Vegetation Cover on Soil Temperature in an Urban Ecosystem. *Soil Science Society of America Journal* .

Szlavecz, K. M., McCormick, M., Xia, L., Saunders, J., Morcol, T., Whigam, D., Filley, T. and Csuzdi C. 2010. Ecosystem effects of non-native earthworms in Mid-Atlantic deciduous forests. *Biological Invasions.* 13 (5), 1165-1182.

Tang, J. M., Misson, L., Gershenson, A., Cheng, W., and Goldstein, A.H. 2005. Continuous measurements of soil respiration with and without roots in a ponderosa pine plantation in Sierra Nevada Mountains . *Agricultural and Forest Meterology* , 212-227.

UNFCCC. 1997. *UNIFCCC.* Retrieved 2010, from Kyoto Protocol: http://unfccc.int/kyoto_protocol/items/2830.php

United Nations. 2009. *United Nations, Department of Economic and Social Affairs, Population Division.* Retrieved 2010, from World Urbanization Prospects: The 2009 Revision: http://esa.un.org/unpd/wup/index.htm

Uusimaa, M. 2003. *Viasala News Articles.* Retrieved November 2010, from Diffusion-Based Soil Respiration: http://www.vaisala.com/Vaisala%20Documents/Vaisala%20News%20Articles/VN163/Diffusion-Based_Soil_Respiration_Measurements_vn163.pdf

Supplementary Data 1

Plot Cover	Plot Name	Days Sampled	Total Days of Sampling	Frequency of Sampling
Forest	444A	14	16	87.50%
	444B	14	16	87.50%
Forest	99A	14	16	87.50%
	99B	14	16	87.50%
Forest	34A	14	16	87.50%
	34B	14	16	87.50%
Forest	441A	16	16	100.00%
	441B	13	16	81.25%
Grass	48A	14	16	87.50%
	48B	14	16	87.50%
Grass	428A	16	16	100.00%
	428B	16	16	100.00%
Grass	44A	16	16	100.00%
	44B	16	16	100.00%
Grass	91A	14	16	87.50%
	91B	14	16	87.50%
Mixed Litter	207A	14	16	87.50%
	207B	15	16	93.75%
Mixed Litter	208A	16	16	100.00%
	208B	16	16	100.00%
Mixed Litter	37A	16	16	100.00%
	37B	16	16	100.00%
Mixed litter	492A	14	16	87.50%
	492B	14	16	87.50%